ARKIV FÖR FYSIK Band 16 nr 12

Communicated 11 March 1959 by H. Alfvén and Kai Siegbahn

First and second harmonics of the daily variation of the cosmic ray nucleonic component at Uppsala Aug. 31, 1956 to Aug. 31, 1957

By Arne Eld Sandström and Stig Lindgren

With 9 figures in the text

ABSTRACT

The neutron pile monitor in Uppsala has 12 proportional counters with 97 per cent enriched $B^{10}F_3$ giving an average counting rate of 420 counts a minute (Aug. 1956). In the present paper the registrations from the first year of running are treated as regards the daily variation. The mean daily variation for every single solar rotation period has been treated as well as the mean daily variation for the whole year. To study the correlation with geomagnetic activity the days were divided into five classes according to their K_p-indices. The first and second harmonics for each class of days were determined for the period Aug. 31, '56 to Aug. 31, '57. The disturbing influence of the sharp intensity drop following the onset of a Forbush decrease concerning the daily variation is discussed specially. The influence is found to be negligible not only as far as the yearly mean is concerned but also as regards the 27 days sun rotation periods. The influence becomes serious only in the case of the most disturbed days when phase and amplitude are studied as functions of the K_p-index. The mean value of the time of maximum is found to be 1300 GMT for the first harmonic and 0530 GMT for the second harmonic. The yearly mean of the amplitude is 0.32 per cent in the first case and 0.034 per cent in the second. The dependence of phase and amplitude on the K_p-index is very small.

Introduction

From the start studies of the time variations of the nucleonic component were made a part of the Swedish cosmic ray project for the IGY. As a first step early in 1955 a small neutron monitor was built at the Royal Institute of Technology, Stockholm. Although intended only for preliminary studies and having as low a counting rate as 32 c/hr this small monitor furnished valuable results during the solar flare effect of February 1956 [1]. It has also been mounted in aircraft [2] for studies of the latitude effect as well as direct determinations of the barometric coefficient of the nucleonic component.

Experience having been acquired construction started on a large monitor designed according to the recommendations for the IGY [3]. The monitor was completed early in the summer of 1956. It was erected in a pavilion on the outskirts of the town of Uppsala specially designed for housing cosmic ray registration equipment. A rather prolonged period of tests followed. The continuous records started on August 31, 1956. Records with abundant breaks are available for some weeks before that date.

Equipment

Fig. 1 displays two cross-sections of part of the monitor. The 12 proportional counters are filled to a pressure of 45 cm Hg with boron trifluoride enriched to 97 per cent B^{10}. The geometry follows the design by Simpson *et al.* [4] with one exception. In our monitor the two end counters are also surrounded by 5 cm of lead on all four sides, whereas in the original design by Simpson *et al.* the two outermost counters have lead on three sides only. For convenience some dimensions were changed slightly when transferring the design to the metric system.

A heavy wooden box filled with paraffin wax serves as a bed directly supporting the pile core of lead. On top and on the sides wooden boxes filled with paraffin constitute the shield and moderator. The paraffin surrounding the proportional counters has been melted into boxes having centered bakelite tubes into which the counters themselves are inserted. The lead for the core is from the Boliden Mining Co. It is very pure and does not contain any measurable quantities of radioactive elements.

The proportional counters were made by AB Atomenergi, Stockholm. By means of the connector boxes they constitute two separate sections, each one containing six counters. All insulating parts in the connector boxes were made of teflon.

Each section of the monitor is served by a complete set of electronics. The preamplifier, main amplifier, and discriminator are the same as those developed by H. Elliott [5]. The stabilized high voltage unit is a commercial one from The Isotope Development Co, Ltd, London (Type 532). The stabilized power supply of 300 V with an output of 100 mA is essentially the same as the Model 50 power supply of Elmore and Sands [6].

Fig. 2 is a block diagram of the electronic circuits. The preamplifiers are mounted as close to each one of the connector boxes as is practically possible. From the discriminator the pulses are fed to a scaler consisting of five Philips decade units. The two scalers are mounted on a panel also carrying a precision aneroid, a clock and two mechanical counters. The whole panel is photographed every full hour. One of the mechanical counters shows the running number of the exposure. The other warns if there has been any power failure between exposures. The clock carries a smal dial for the date.

On the photographic film the aneroid can be read to the nearest 0.1 mb (by direct visual reading a theoretical accuracy of ± 0.05 mb is possible). A micro-barograph serves as an auxiliary means of determining the pressure. Should both instruments be out of order it is still possible to calculate the missing data from the records of a nearby meteorological observatory.

In the case of single events such as a solar flare effect it becomes necessary to have access also to data for comparatively short registration periods. For the IGY 15 minute intervals were recommended. However, experience from the event on February 23, 1956 showed that there might be cases when even shorter intervals are desirable. It does not suffice, therefore, to increase the camera exposures to four times every hour. At the same time an auxiliary equipment for short interval registrations should also furnish means of avoiding gaps in the data in case of breakdowns of the

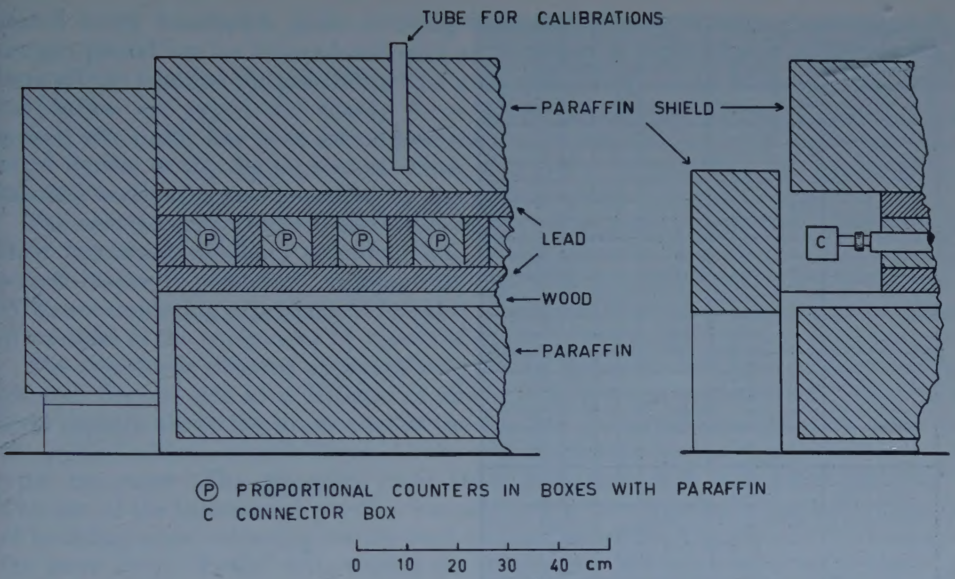

Fig. 1. Cross sections of the neutron pile monitor showing the essential details of the paraffin shield and the positioning of the lead core and counters.

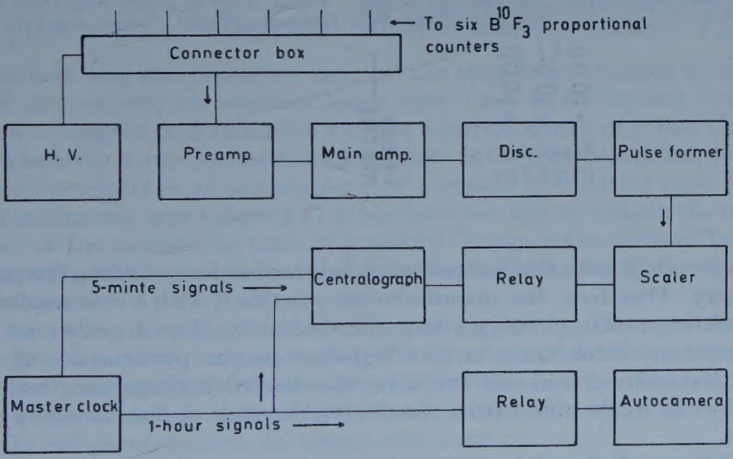

Fig. 2. Block diagram of the neutron monitor circuits.

main registration equipment. To serve the complete set of instruments with the same sort of auxiliary outfit we were faced with the problem of the simultaneous recording of at least fourteen separate channels.

A versatile apparatus meeting these demands was found in the so called centralograph of the L. M. Ericsson Telephone Co. The recording part of this apparatus consists of 20 electromagnetically operated levers typing series of dashes on a strip of

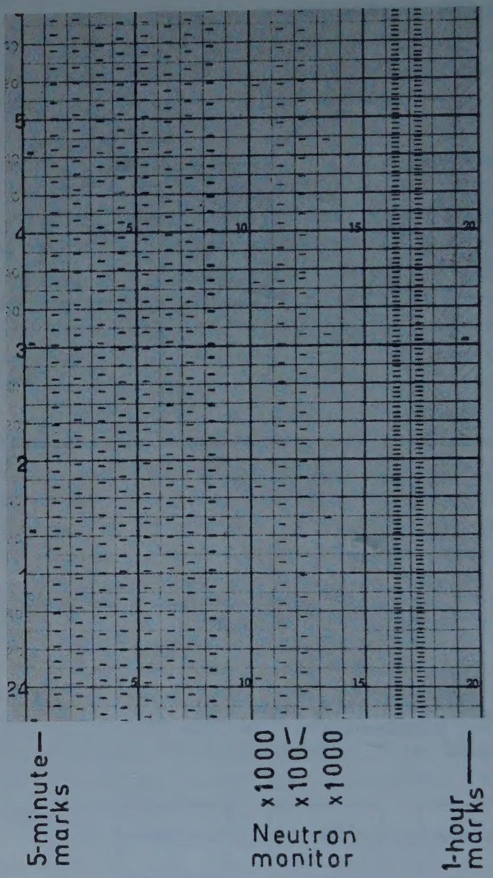

Fig. 3. Part of paper strip from the auxiliary recording outfit ("centralograph").

moving paper. Originally the centralograph is intended for recording the performance of machinery. Therefore, the manufacturers provide it with a continuously working pulse-generating arrangement printing the dashes so close together as to form a broad continuous black trace until a signal stops the performance of the pulse-generator. Naturally, in our case the latter was discarded altogether, the levers being operated by the single pulses from the twelve channels of our cosmic ray recording equipment.

From the second figure in the digital scaler the outgoing pulses are also fed through a single tube amplifier to a univibrator. An electro-mechanical relay in the anode circuit of the latter operates the 24 volts line necessary for working the lever-system of the centralograph. Time signals are recorded in the two side columns on the recording paper (Fig. 3). Every fifth minute is marked on the left side and every hour on the right. The time signals are furnished by the master clock operating the camera in front of the instrument panel.

The recording paper runs with a speed of 1 cm a minute. The 5-minute marks make it possible to operate with periods as short as half a minute, if desirable. As already stated every hundredth pulse is being recorded. The number of pulses during a certain period can be interpolated with an accuracy of ±20. Experiences from solar flare effects point to the possibility that even with a scale of 100 it might happen that the dashes are typed too closely for a proper separation. Recently, therefore, a second relay-unit has been introduced making it possible to record pulses from the third figures of the digital scalers. Thus, also every thousandth pulse from the two monitor sections is now recorded by the centralograph.

The centralograph records have turned out to be a very great help regardless of their furnishing auxiliary records. Thus, at any time an inspection of the running record makes it possible to compare the performance of the two monitor sections. With accumulating experience it has also turned out to be possible to trace the causes of troubles in the equipment by means of characteristic irregularities in these records.

The monitor is situated approximately 60 cm above the immediately surrounding ground. On one side at a distance of about 20 m there is a granite rock rising to a level slightly above the upper part of the monitor. In winter time the snow cover on the ground seldom exceeds 30 cm. All the roofing consists of wooden materials covered with tar-paper. The screening mass above the monitor is well below 20 gcm^{-2}. The site of the instrument pavilion was selected so as to get the best possible chances of avoiding snow collecting on the roof during the winter. Usually the wind sweeps the snow away. Twice, only, during the first winter did snow have to be removed from the roof. In both cases a cover of wet snow less than 10 cm thick had collected during the night. In none of these events could any systematic influence be detected.

Adjustments and calibrations

The amplifiers and discriminators have all the time been adjusted so as to allow pulses from the proportional counters larger than 1 mV to be counted. The monitor is calibrated by means of a radium-beryllium neutron source of 1 mc. Calibrations are made whenever a readjustment of amplifiers or discriminators has taken place as well as after repairs or at any suspicion of a change of counting rate. No regular schedule of calibration was followed as it has been our aim to disturb the continuous performance of the monitor as little as possible. Owing to the sections being inside the same paraffin shield one section cannot be calibrated without affecting the counting rate of the other.

Usually the two monitor sections are calibrated separately. The tubes for positioning the neutron source are approximately 15 cm above the center of each section (Fig. 1). There is an auxiliary tube at the center of the monitor. The length of each calibration run was at first half an hour. Later it was reduced to 25 minutes thus confining the whole calibration to within one hour.

The two monitor sections have approximately equal counting rates as far as cosmic rays are concerned. Owing to some slight displacement of the calibration tubes from exactly symmetrical positions the counting rates of the two sections differ when exposed to the radiation from the neutron source.

The background of the counters (together with accidental high energy neutrons produced outside the monitor) was tested by means of cadmium covers on the proportional counters [4]. The counting rate was found to be constant all along the plateau of the counters. It amounted to 4 per cent of the normal counting rate with the cadmium tubes removed.

The primary data

The normal counting rate of the monitor is 420 counts a minute.

From Aug. 31, 1956 to Aug. 31, 1957, inclusive, only eight days are affected by breaks in the records of such an extent as to make them unsuitable for the harmonic analysis of the daily variation. In a few instances days could be saved for this analysis by interpolating values for single hours or in a few cases two consecutive hours. In such cases great care has been excercised. In no case single events or abrupt intensity changes are known to have taken place during the interval for which such an interpolation was performed. Altogether values have been interpolated for only 44 hours out of a total number of 8592.

All data have been referred to intervals of 2 hours. They have been reduced to an atmospheric pressure of 1010 mb (over a 60 year period the yearly average for Uppsala is reported to have been 1008 mb). The pressure coefficient is -0.00737. This is the generally adopted value. The very similar value of -0.00738 was found from direct measurements by means of an airborne monitor flown above Uppsala in 1957 [2]. The exponential barometric formula has been employed.

The harmonic analysis has been carried out by means of the electronic computing machine BESK in Stockholm. As the time of maximum as well as the amplitude are being determined by thirteen 2-hour values the statistical fluctuations will contribute to the limits of errors with an amount somewhat less than the fluctuations of each single 2-hour period. This contribution is easily calculated from the harmonic coefficients and the average counting rate [7].

The reason for selecting a yearly period starting with Aug. 31, 1956 is simply due to the fact that registrations started in Uppsala at this time and that with the end of August 1957 another Swedish monitor started producing data from an Arctic station at Murchisonbay, Svalbard. Further results from both monitors will be published in a following paper [8].

The daily variation

In Fig. 4 the yearly mean of the daily variation of the nucleonic component is given in per cent of the average intensity. The statistical fluctuations are ± 0.025 per cent for each one of the points of measurement. The first and second harmonics are included for comparison. The later are illustrated by the clock diagrams in Fig. 5, aslo. The circles indicate the uncertainty due to the statistical fluctuations.

The 12 months covered by this paper are remarkable for a large number of Forbush decreases. Certainly such a decrease will mask the true time of maximum for at least the day on which it starts and, perhaps, also for the next day. It is doubtful if an ordinary trend correction will remove the disturbance. Then, it is also possible that a shift of the time of maximum as well as an increase in amplitude will become distinguishable in the yearly mean or, more probable, in the 27-day means. Naturally it is of considerable interest to ascertain if such a shift in time and amplitude exists and, if that is the case, the magnitude of this shift. Therefore a separate harmonic analysis was carried out on the same sets of data as before, but with those days excluded on which Forbush decreases started or on which their downward slopes continued. The days thus excluded are listed in Table 1.

Concerning the yearly mean there is no displacement at all of the time of maximum and the change in amplitude is less than the influence of the statistical fluctuations.

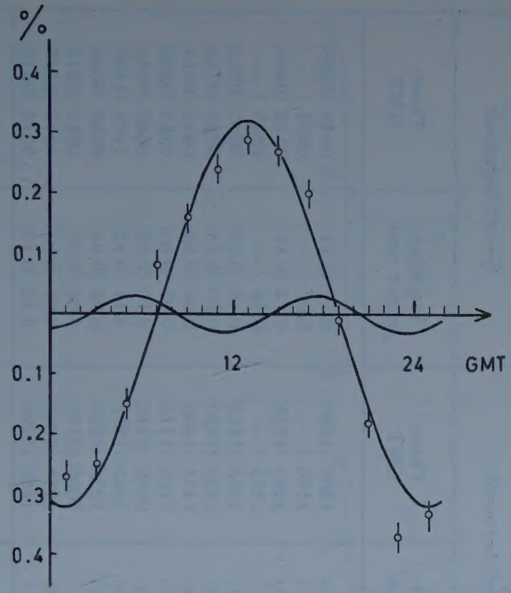

Fig. 4. First and second harmonic for the mean daily variation during the period Aug. 31, '56 to Aug. 31, '57 in per cent of the daily average. The statistical fluctuations are indicated at each experimental point derived from the 2-hour values of the neutron monitor records.

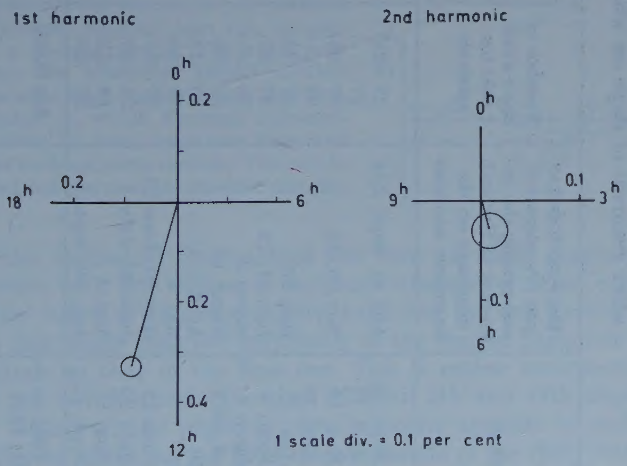

Fig. 5. Clock diagrams for the first and second harmonics of the mean daily variation during the period Aug. 31, '56 to Aug. 31, '57.

In general there is no significant phase shift of the first harmonics of the mean daily variation of the solar rotational periods either (Table 1). Period number 1694 is an exception. In this case there is a shift of seven hours. However, due to the fact that during this period the amplitude of the first harmonic is of the same order of

Table 1. Amplitude and phase of the daily variation. The numbers in parentheses are those values which were obtained after removal of days on which Forbush decreases started.

Sun rot. number	Period	Days excluded in the investigation concerning the influence of Forbush decreases on the harmonic analysis	Number of days available for analysis	First harmonic		Second harmonic	
				Amplitude in per cent	Phase GMT	Amplitude in per cent	Phase GMT
1686	Aug. 31–Sept. 26	Aug 31, Sept. 2, 8	27 (24)	0.37 (0.36)	1400 (1330)	0.11 (0.11)	0645 (0630)
1687	Sept. 27–Oct. 23	—	27 (—)	0.56 (—)	1400 (—)	0.07 (—)	0600 (—)
1688	Oct. 24–Nov. 19	Nov. 9, 15	27 (25)	0.44 (0.38)	1245 (1245)	0.15 (0.11)	0415 (0400)
1689	Nov. 20–Dec. 16	—	27 (—)	0.32 (—)	1215 (—)	0.10 (—)	0245 (—)
1690	Dec. 17–Jan. 12.	Dec. 25	27 (26)	0.22 (0.21)	1345 (1415)	0.14 (0.12)	0915 (0915)
1691	Jan. 13–Febr. 8	Jan. 21, 22	27 (25)	0.37 (0.32)	1315 (1330)	0.20 (0.19)	0645 (0745)
1692	Feb. 9–March 7	March 2	26 (25)	0.35 (0.38)	1415 (1400)	0.08 (0.09)	0015 (0015)
1693	March 8–April 3	March 10	27 (26)	0.26 (0.27)	1100 (1115)	0.07 (0.05)	0345 (0300)
1694	April 4–30	April 5, 17	25 (23)	0.12 (0.05)	0830 (0145)	0.10 (0.12)	0545 (0545)
1695	May 1–27	May 8	27 (26)	0.25 (0.28)	1245 (1230)	0.11 (0.12)	1100 (1100)
1696	May 28–June 23	May 30, June 23	27 (25)	0.27 (0.26)	1230 (1230)	0.04 (0.04)	0030 (0000)
1697	June 24–July 20	June 30, July 1	25 (23)	0.32 (0.27)	1000 (1100)	0.04 (0.08)	0015 (0215)
1698	July 21–Aug. 16	Aug. 4	24 (23)	0.42 (0.38)	1245 (1245)	0.07 (0.06)	0545 (0545)
1699	Aug. 17–Sept. 12	Aug. 29, Sept. 2	27 (25)	0.53 (0.45)	1400 (1400)	0.12 (0.10)	0315 (0315)
	Aug. 31, 1956 to Aug. 31, 1957		358 (339)	0.32 (0.30)	1300 (1300)	0.03 (0.02)	0530 (0515)

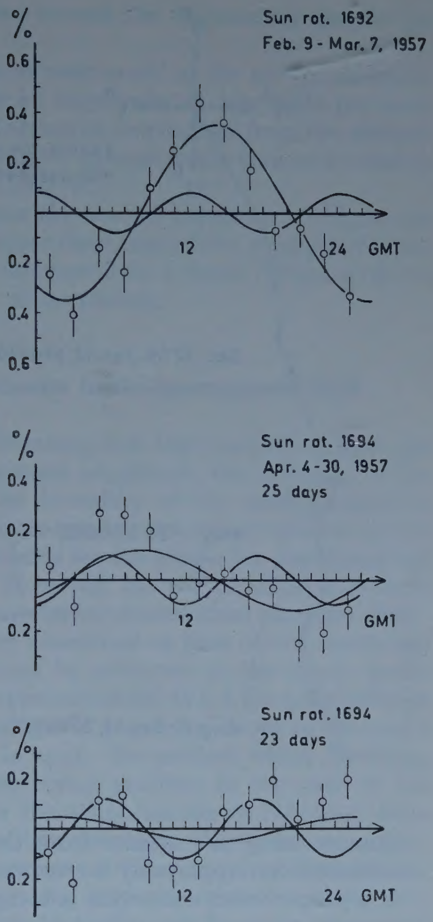

Fig. 6. First and second harmonics for sun rotation periods. The uppermost diagram (sun rot. number 1692) illustrates a normal period. The two lower diagrams illustrate the abnormal period number 1694 with all available days (upper curve) and with those days excluded on which Forbush decreases started (lower curve). In both cases two days had to be excluded due to incomplete records. The points refer to the values from the neutron monitor records.

magnitude as the statistical fluctuations the time of daily maximum cannot be regarded as known with any degree of accuracy whatsoever. This is accentuated by the shape of the curve of the mean daily variation for this period (Fig. 6). It is evident that in this single case the amplitude of the second harmonic is of the same order of magnitude as that of the first one. This is rather unexpected as the days following upon the two Forbush decreases of April 5th and 17th display prominent daily maxima. However, the phase of these maxima appears to shift from day to day. During the rest of the period 1694 the amplitude of the daily variation appears to be unusually small.

As regards the second harmonic the removal of days with Forbush decreases does not seem to affect the phase at all, not even in the case of the period 1694.

In some cases the amplitude of the first harmonic becomes smaller by the removal of days with Forbush decreases (Table 2). Although the difference can be as big as 15 per cent it scarcely exceeds the uncertainty due to the statistical fluctuations. The small increases in some instances are certainly all to be ascribed to those fluctuations.

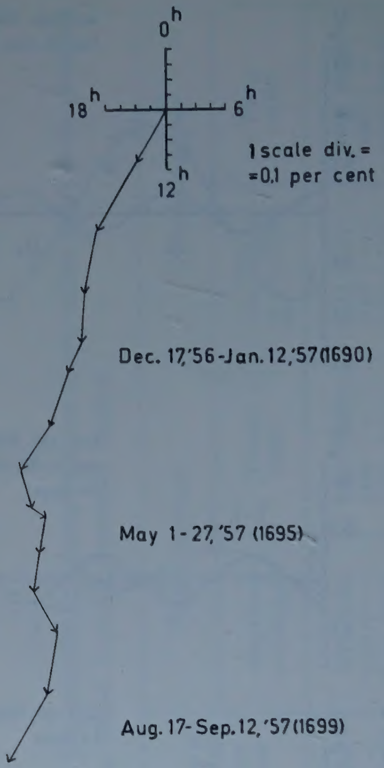

Fig. 7. Vector sum diagram of the first harmonic for 14 consecutive sun rot. periods Aug. 31, '56 to Sept. 12, '57.

Summarizing the results from the preceding comparative study the following conclusions can apparently be drawn:

If a proper trend correction is being applied the Forbush decreases will not affect the yearly mean of the daily variation. Likewise, they will generally not affect the mean daily variation of the sun rotation periods.[1] It is doubtful, however, if the trend correction will suffice concerning the mean daily variation in cases where the majority of days are such on which Forbush decreases occur. This special case will be treated in the section on the phase of the daily variation as a function of the K_p-index.

The vector sum diagrams of Fig. 7 illustrate how the amplitude and time of maximum of the first harmonic varies from one sun rotation period to another. The variations are comparatively small as to phase, most of them being covered by the statistical fluctuations. The only exception once again being the rotational period number 1694. The amplitude varies between a maximum value of 0.56 per cent and a minimum value (during the aforementioned period) less than the statistical fluctuations. In the majority of cases the amplitudes exceed the uncertainty due to the statistical fluctuations by a factor of 3 to 8.

---

[1] It is of some interest to note that if the trend correction is being omitted then a phase shift takes place when days with Forbush decreases are excluded. This is an indication that as far as the nucleonic component is concerned the trends are mostly associated with the decreases. Also, the tests and calibrations peculiar to the neutron monitor exclude any instrumental drift.

The second harmonic of the daily variation is very small as far as the nucleonic component is concerned. The yearly mean has an amplitude of only 0.034 per cent. This value is undoubtedly outside the limits of errors as determined from the statistical fluctuations, although with a very narrow margin. As regards the time of maximum the accuracy has to be regarded as very small (Fig. 5).

In general it becomes meaningless to discuss the second harmonic of single sun rotation periods. The amplitudes are indeed bigger than that of the yearly mean but at the same time the statistical fluctuations increase 3 to 4 times. There is also a tendency to random distribution of the time of maximum.

Correction for the deviation of the primaries in the geomagnetic field

Through the work by Brunberg [9] and by Brunberg and Dattner [10] we have got the means of determining, at the time of maximum amplitude, the direction of the trajectories of the cosmic ray primaries at the boundary of the earth's magnetic field. The cited investigations deal with a dipole model and recent studies of the latitude effect [11] have shown that such a model is far too simple for describing the geomagnetic effects on cosmic ray primaries. However, the complications probably concern the cut off energies more than the trajectories of individual particles. Especially where as high geomagnetic latitudes are concerned as that of the cosmic ray station in Uppsala (58°36′) the errors introduced by reference to the dipole model will certainly not become too serious for a first approximation. It is a far more difficult problem to determine the rigidity to be ascribed to the primaries. As far as the nucleonic component is concerned it is impossible to apply the method which Brunberg and Dattner employed for solving the corresponding problem in the case of the meson component [12]. In a more recent paper Brunberg has shown [13] that, even for the meson component, the determination of the true correction involves complicated calculations. In the case of a neutron monitor we still lack much of the information necessary for these calculations. We do not even know the deviation in the geomagnetic field of primaries with rigidities below 10 GeV/c and finite zenith angles. A rough estimate puts the upper limit of the rigidity of the primaries below 15 GeV/c. The geomagnetic cut off towards low rigidities is usually estimated to 2 GeV/c for latitudes above the knee of the intensity-latitude curve. However, during the last few years the cut off appears to have suffered a shift towards increasing rigidity values [14].

Brunberg has published corrections for a number of ridigidities and directions for places where cosmic ray intensity registrations are being performed [15]. One of these is Stockholm which is sufficiently close to Uppsala for being applicable to the data presented in this paper. The difference in geomagnetic latitude between the two places is only 15′. We regard the vertical as the axis of detection of the monitor. Measurements by Malmfors [16] enabled Brunberg to extend his curve for the zenith direction in Stockholm down to 2 GeV/c. Fig. 31 in Brunberg's paper [15] reveals that there is no appreciable shift of the longitudinal correction angle from 15 GeV/c and down to 10 GeV/c. From 5 GeV/c and downwards the correction increases fast with decreasing rigidity. With due regard for what has been said about the low energy cut off, it can certainly be assumed that the "effective rigidity" is at least 3 GeV/c. It follows from this discussion and Fig. 31 in Brunberg's paper [15] that the longitudinal correction is confined to angles between 52° and 90°. The probability is small that it will be close to any one of these limits. Therefore, it might be put to $(71° \pm 15°)$ E. As the longitude of Uppsala is 18°E, the secondaries with vertical impact directions relative to the monitor are produced by primaries entering the geomagnetic field around a plane through long. $(89° \pm 15°)$ E. As already shown by Table 1 and Fig. 5 the yearly mean of the daily variation has its maximum at $13^{h}00^{m} \pm 20^{m}$ GMT. Consequently, the primaries make an angle towards the afternoon direction of $104° \pm 20°$ with the meridian plane through the radius vector from the sun. The limits of errors ascribed to the time of maximum are only those due to the statistical fluctuations. We are fully aware of the fact that there might be other sources of errors which tend to increase these limits. We hope, however, that these additional errors will not seriously affect the total limits of errors as the estimated ones for the correction angle are very wide. As a result of the wide limits of errors there will be no meaning in trying to resolve the first harmonic into components as has been done, where mesons were concerned [17].

The first daily maximum of the second harmonic appears (7.5 ± 1.0) hours before that of the first harmonic. If we assume that the rigidity of the particles is the same in both cases this would mean that there is an excess of particles coming in also at an angle with the radius from the sun of $9° \pm 30°$ in the morning direction and $189° \pm 30°$ in the afternoon direction indicating the existence of a noon component as well as a midnight component.

The phase of the daily variation as a function of the K_p-index

One of us [7] correlated the meson component with the planetary geomagnetic character figure K_p. As far as we have been able to ascertain no corresponding treatment of the nucleonic component has as yet been published. Therefore it was with considerable interest we started such a study based on our neutron monitor data. The days were divided into classes according to their maximum K_p-index in the same manner as described in the study just mentioned [7]. This manner of grouping the days according to K_p-index is illustrated by Table 2. It is negligible if the division into classes is founded on the daily maximum K_p-index or on the sum of the K_p-indices for that particular day [17].

Table 1. Classes of days according to K_p-index.

Class	K_p-index max. value	Number of days
I	$0 < [K_p]_{\max} \leq 1^+$	14
II	$1^+ < [K_p]_{\max} \leq 3^+$	145
III	$3^+ < [K_p]_{\max} \leq 5^+$	147
IV	$5^+ < [K_p]_{\max} \leq 7^+$	42
V	$7^+ < [K_p]_{\max} \leq 9^0$	10

The amplitude and the phase corresponding to each one of the K_p-index classes can be read from the clock diagram in Fig. 8. As in the case of the yearly mean and

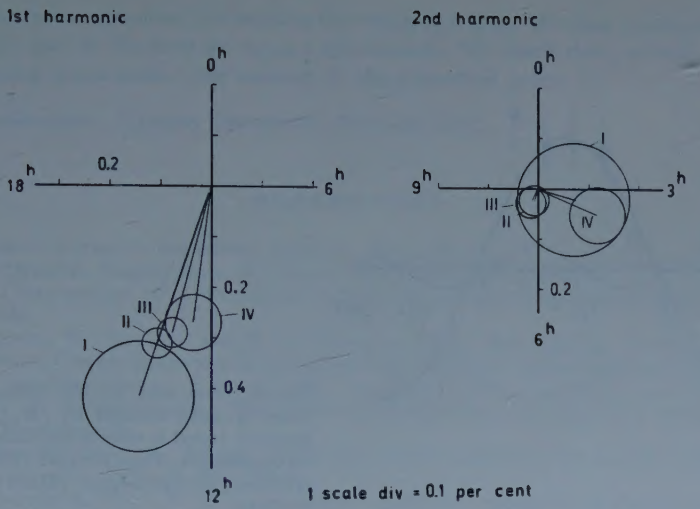

Fig. 8. Clock diagrams for the first and second harmonics for days divided into classes according to maximum K_p-index.

the sun rotation periods a special study was made concerning the possibility of the Forbush decreases affecting the phase or the amplitude in those classes of days where the number of disturbed days becomes considerable. Days with the start of a prominent Forbush decrease do not appear in the two first classes where $[K_p]_{\max} \leq 3^+$. They are very few also in the next class where $3^+ < [K_p]_{\max} \leq 5^+$. Even concerning the class of days with $5^+ < [K_p]_{\max} \leq 7^+$ there is no detectable influence although Forbush decreases start on 10 per cent of the total number of days. The most disturbed days (class V) are nearly all of them such days on which decreases took place or on which the steep downward slope still continued. A study of any intensity-time curve of a Forbush decrease proves the difficulty encountered in tracing the true daily variation in these cases. As there is only one day (March 29) of normal character it is impossible to carry out the same kind of comparison as for the yearly mean and for the mean daily variation of the sun rotation periods. It is too hazardous to introduce any kind of correction for the decrease itself.

It is interesting to note that the difference in phase is very small between the four classes of days having $[K_p]_{\max} \leq 7^+$ (Fig. 8). Taking the statistical fluctuations into account as shown by the circles in Fig. 8 it is doubtful if there is any phase shift at all. However, the small displacements of the four vectors are in the same direction as found in the early study of the meson component already mentioned [7]. In the latter case the vectors for classes II and III did also fall close together but in this instance there was a definite phase shift to late hours for days with $[K_p]_{\max} \leq 1^+$ and a corresponding phase shift to early hours for $5^+ < [K_p]_{\max} \leq 7^+$.

To correct for the deviation of the primaries in the earth's magnetic field we will have to assume that the effective value of the rigidity of the primaries is the same regardless of the geomagnetic disturbances. Owing to the small variations in phase the vectors of classes I to IV can all be considered as making the same approximate angle of 104° with the noon direction. The limits of errors mask all indications of a radial component varying with the K_p-index. [17].

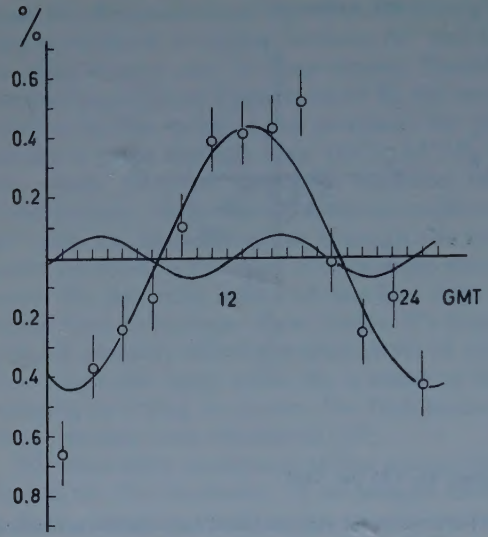

Fig. 9. First and second harmonics for the class of days defined by $[K_p]_{\max} \leqslant 1^+$. The positive trend is clearly indicated by the relative positions of the 1st and 13th points corresponding to the 2-hour values of the monitor records.

The big amplitude on days belonging to class I makes the accuracy of the harmonic analysis satisfactory although there are only 14 days with $[K_p]_{\max} \leqslant 1^+$. From Fig. 9 can be seen that the amplitude does not arise from some few points accidentally deviating with a large amount from the daily mean. Accordingly the difference in amplitude between days of class I and of class IV might be real.

Fig. 9 illustrates also another interesting fact. By comparing the 1st and 13th points it becomes evident that the trend is positive. This indicates that in general these magnetically very quiet days are to be found on the return slope after Forbush decreases.

As regards days with $[K_p]_{\max} \leqslant 5^+$ the amplitude of the second harmonic is so small as to be negligible in comparison with the statistical fluctuations (Fig. 8). Apparently the time of maximum amplitude has to be regarded as undetermined.

The picture changes when we turn to days where $5^+ < [K_p]_{\max} \leqslant 7^+$. Here the amplitude of the second harmonic is sufficiently big for a comparatively satisfactory determination of the phase. The first maximum will appear 9 ± 1 hours before that of the first harmonic for the same K_p-index class of days. This is practically the same phase difference as for the yearly mean of the daily variation for all days regardless of their geomagnetic character figure.

ACKNOWLEDGEMENTS

Funds for the monitor were granted jointly by the Swedish Natural Science Research Council and the Atomic Energy Committee. A grant from the Reserve Fund of Uppsala University made it possible to build and equip the instrument pavilion.

The research concerned in this paper is supported in part by contract AF61(514)–1312 with the Air Research and Development Command, USAF, through its European Office.

We are indebted to Dr. D. Eckhardt, at that time at the Royal Institute of Technology, Stockholm for valuable help with the electronics of the monitor.

Mr. Ole Edvardsen supervised the work in the electronics shop. Mr. Eric Dyring and Mr. Lars O. Ericson took part in the final set up and ajdustments. We thank them as well as the ladies in our computing department, who assisted in the numerical work.

Fysiska Institutionen, Uppsala Universitet, February 1958.

REFERENCES

1. D. Eckhardt, Letter to the editor, Tellus *8*, 281 (1956).
2. A. E. Sandström, Supplemento del Nuovo Cimento, *8*, 263 (1958).
3. Bulletin d'Information n° 4 du Comité Spécial de l'Année Géophysique Internationale, p. 158 (1955).
4. J. A. Simpson, W. Fonger, and S. B. Treiman, Phys. Rev. *90*, 934 (1953).
5. J. A. Simpson, Cosmic Radiation Neutron Intensity Monitor. Report prepared at the request of the Sub-Commission of Cosmic Ray Intensity—Time Variations (of IUPAP). The Institute for Nuclear Studies, The University of Chicago, January 1955 (Multiplied typewritten manuscript).
6. W. C. Elmore and M. Sands, Electronics, New York–Toronto–London 1949, p. 372.
7. A. E. Sandström, Tellus *7*, 204 (1955).
8. A. E. Sandström, Eric Dyring, and Stig Lindgren, Tellus, in preparation.
9. E. Å. Brunberg, Tellus *5*, 135 (1953).
10. E. Å. Brunberg and A. Dattner, Tellus *5*, 269 (1953).
11. P. Rothwell, Suppl. del Nuovo Cimento VIII, 249 (1958);
    A. E. Sandström, Ark. f. Fysik *14*, 409 (1958).
12. E. Å. Brunberg and A. Dattner, Tellus *6*, 73 (1954).
13. E.-Å. Brunberg, Arkiv f. Fys. *14*, 195 (1958).
14. P. Meyer and J. A. Simpson, Memoria del V Congreso Internacional de Radiacion Cosmica, 161, México 1958.
15. E. Å. Brunberg, Tellus *8*, 215 (1956).
16. K.-G. Malmfors, Arkiv f. Matemat., Astr. o. Fys. *32* A, No. 8 (1945).
17. A. E. Sandström, Tellus *8*, 18 (1956).

Tryckt den 8 juli 1959

Uppsala 1959. Almqvist & Wiksells Boktryckeri AB